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A methodology to determine and classify data sharing requirements between OpenBIM models and energy simulation models

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Energy analysis at different stages of a building's life-cycle allows designers and engineers to make proper design decisions, which will enhance the efficiency and energy saving measures. However, energy analysis of a building using traditional methods at every stage of the project is time-consuming and more labor intensive. Thus, energy simulations of buildings are rarely introduced in all design stages of the project. This study focuses on data transfer process from BIM model (Revit) to energy simulation model (IES<VE>) using OpenBIM meta-data model - Industry Foundation Classes (IFC) as an exchangeable file format. This data sharing process simplifies the complexity in energy modeling and allows to investigate different design alternatives in each phase of the building's life-cycle. To investigate the efficiency and completeness of this data transfer process, a demonstration of data sharing is carried. By evaluating the results from the demonstration, efficiency gaps are identified in the data transferred process. A detailed investigation on the cause of efficiency gaps in data sharing is carried out and incorporated in this paper.

Keywords: BIM, energy model, IFC, data sharing, efficiency gaps

1 Introduction

Building Information Modeling (BIM) leads to significant changes of the design process by introducing building energy analysis in the early stage of the project and thereby bridging the distance between evolution and design (Karen M and Douglas, 2014). BIM models contain a large range of information regarding the product and process. The linking of these BIM models to building energy models will enable an access to the information required for energy simulation and eliminates the need for creating an energy simulation model (Moon et al., 2011). This integration creates a large range of advantages in the energy modeling process.

- BIM-based energy analysis allows iterative simulations for a wide range of scenarios to be performed within a short period of time.
- The time saving from the reproduction of the energy simulation model could be spent on the simulation and design options (Moon et al., 2011).
- The geometrical changes in the BIM model can be easily reflected in the energy analysis model by recreating or generating the energy model quickly with the help of BIM program.

This research starts with an investigation of different approaches and methodologies for energy simulation in buildings and performs a categorization of these methodologies according to the scope and complexity of data processing. The major purpose of these investigations is to analyze the information requirements for energy simulations.

In the process of integration between BIM models and simulation models, efficient data sharing is the key concept to establish the successful implementation of the data transfer process. The efficiency in data sharing is improved along with the development of a BIM meta-data model or a data exchange schema such as IFC. So, the research further continued with the investigation of data sharing requirements for the OpenBIM model (IFC), in order to transfer the analyzed information to an energy simulation model.

Furthermore, a demonstration of the data exchange is performed to analyze or map the investigated results with the practical data transfer process. All the information requirements are incorporated into a building information model as input parameters to leverage the model and then the data transfer process is carried out to investigate the potential of BIM-based energy modeling.

2 Building Energy Simulation

Building energy simulation is a methodology to assist engineers, designers and operators to provide more value on the comfort and needs of building owners and occupants. The energy simulation process is a method to analyse the energy consumption of buildings which will assist in making appropriate design decisions.

2.1 Categorization of Energy Simulation Models

There are several types of energy simulation models used to perform energy consumption calculations. All these models are categorized according to three major principles (Table 1).

Table 1: Phenomena analyzed for building energy simulation (Menzel, K; Ploennigs, 2015)

Physical Principles	Level of Abstraction	Time-dependency
Thermal Radiation	Mono-Zone Models	Steady-state Simulation Models
Conduction	Multi-Zone Models	Dynamic Simulation Models
Convection/Advection	Zonal Models	
	CFD Models	

Mono-Zone Models represent the highest level of abstraction, i.e. the lowest level of details. Generally, these kinds of simplified models are used in the early design stages for the calculation of the energy consumption. **Multi-Zone Models** are mostly similar to the Mono-Zone models in terms of modeling the outer shell of the building but additionally, spaces are modeled to separate the building into different analysis zones.

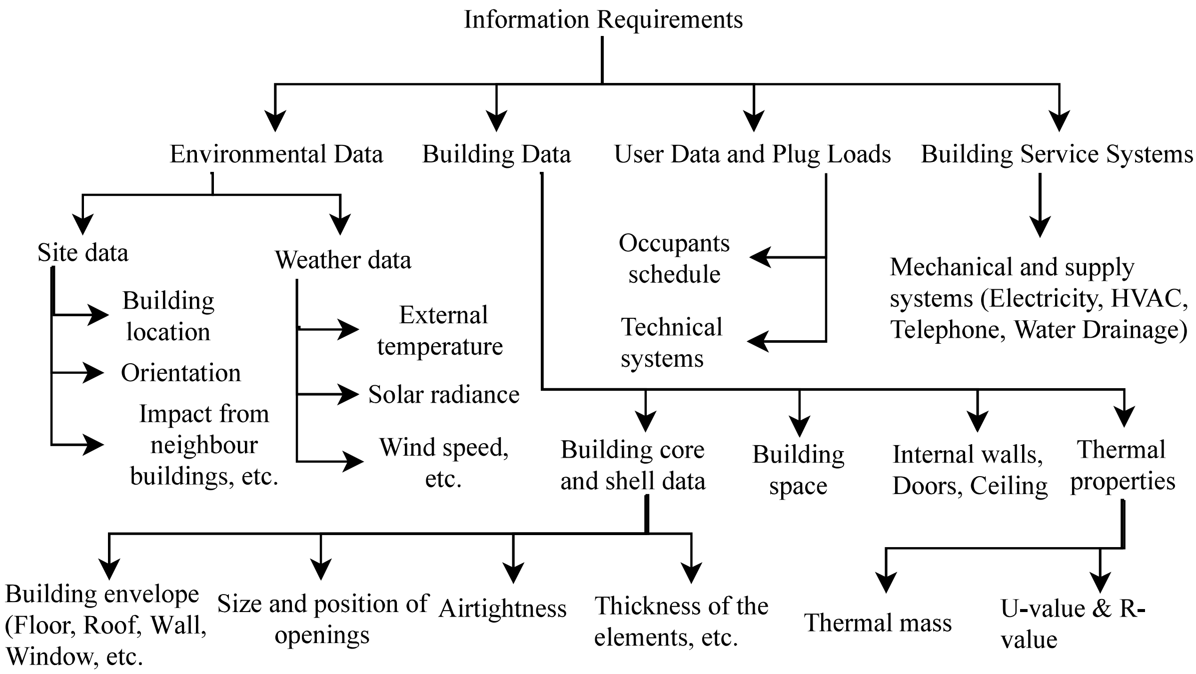

Figure 1: Information requirements for building energy simulations

In the case of **Zonal Models**, a single space operated under a set of constraints is divided or decomposed into multiple modeling zones. **CFD** (Computational Fluid Dynamic) model is a micro level investigation. It provides an option to model a single space with high granularity using a high level of data. CFD analysis provides a greater understanding of the airflow and the heat transferring processes occurring within and around the building spaces (Wimmer et al., 2018).

The difference between **Steady-state** and **Dynamic simulations** is dependent on the input parameters. For Steady-state simulations, all the input parameters are constant throughout the simulations. For Dynamic simulations, the input parameters vary over time during the simulations.

The requirement of input data for energy simulation is dependent on the different design phases of the building's life-cycle. Figure 1 represents some basic information requirements to set up an energy simulation model which is used to determine the energy consumption of the building. These requirements are identified based on complex types of simulation models such as multi-zone model and dynamic simulation model. The same data will be incorporated in the BIM model for the demonstration of the data transfer process. Similarly, the data sharing requirements for this information are investigated in the OpenBIM meta-data model to verify the quality of the data transfer process.

3 Data Sharing Requirements - IFC

buildingSMART proposes an open data scheme called IFC to store, manage and exchange the building information between multiple stakeholders throughout the life cycle of any built environment irrespective of the software being used (BuildingSMART, 2016). This information exchange format allows data interoperability between BIM models and energy simulation models and also increases the transparency of the data transfer process, since the language is both machine and human readable (Bahar et al., 2013).

In order to achieve successful data sharing, the IFC schema is defined or structured based on two major modeling concepts namely Inheritance Hierarchy and Objectified Relationships. Inheritance facilitates the introduction of hierarchies in the BIM model and is an alternative way to arrange the model components in BIM. It supports the reuse of modeling concept (code) since one class (child) is based on another class (parent). Objectified Relationships is another major modelling method in the IFC data schema. *IfcRelationship* entity is the super type for all relationships in the IFC data schema.This entity defines the relationships among different entities, elements and properties.

After the clear understanding of IFC modeling concepts, this research further continues with investigating the data sharing requirements defined in the IFC schema (ISO16739-1 (2018)) with respect to the energy simulation domain to enable an efficient data transfer process. IFC schema is inherently complex and extensive to carry most of the exchange data. Similarly, a BIM model can be equipped with enormous data related to all disciplines of the construction industry, but all data is not necessary for a specific business process. For this purpose, Model View Definitions (MVD) were introduced by buildingSMART to share specific data for a particular process based on the requirements. MVD is a subset of IFC schema, which supports or specifies data exchange requirements for a particular process (ISO29481-1 (2016)).

An investigation is performed to identify data entities defined in IFC schema (ISO16739-1 (2018)) particularly for the information requirements defined in section 2. Similarly, the other part of the investigation is to identify the relationships between these entities defined in the IFC schema, which completes the definition of BIM data in IFC format. Later, these investigation results are used to map with the demonstrated example building's (section 4) IFC file to verify the quality and efficiency of the data transfer process. These results can be used as a reference to identify whether the data is transferring according to the IFC standard definitions or not.

4 Data Sharing Demonstration

A demonstration of data sharing between a BIM tool (Revit) and an energy simulation tool (IES<VE>) using IFC as an interoperability file format is performed to investigate the following,

- Level of data sharing (quality of data it is going to transfer),
- Implementation of meta-model data schemas in a BIM tool (Revit) for data export process,
- Capability or adaptability of simulation tool (IES<VE>) to import the data from IFC.

4.1 BIM model

A three-storey simple office building (refer to Figure 3) with three different spaces or rooms in each floor is modeled in Autodesk Revit 2019 and is incorporated with all the necessary information (mentioned in Figure 1) required for energy simulation. This comprehensive BIM model is exported from Revit to IFC file format for further import processes.

Figure 2: Data transfer methodology

4.2 Data investigation with model viewer

The Solibri Model Viewer tool is used to import the IFC file for the purpose of a data quality check by verifying the available data in the IFC file exported from Revit (three-storey simple office building). This data quality analysis is performed based on the successful import of building geometry, spaces, systems, openings, schedules, material, etc. to Solibri Model Viewer. Based on the investigation results, it is observed that most of the information modeled in Revit is successfully exported to IFC and the same is imported to Solibri Model Viewer. For example, the geometry of the building, material and construction details are efficiently transferred to the IFC file format.

On the other hand, some issues regarding the representation of space type and shading device in the building are identified in Solibri Model Viewer. The IFC schema treats space type as a building type object (*IfcSpaceType*) but in this example it is not represented as a type object, which can be observed in the components list mentioned in "Default" hierarchy of Solibri. It is observed that space type of a particular space is defined as a property which is mentioned under Energy Analysis options in Solibri. After a thorough investigation of the IFC STEP (Standard for the Exchange of Product Model Data) file, it is found that even in the IFC file the space type is defined as a property for a space using *IfcPropertySingleValue* entity in IFC schema. Further, this investigation is extended to check the modeling criteria of space type in the BIM Model. It is noticed that during the process of modeling in Revit, the space is defined as an object for the room and the space type is defined as an object property for that space. Furthermore, some more properties (like area per person, occupancy schedule, heat gains, etc.) are defined as a property of a space based on the space type.

Similarly, another issue observed is with parapet wall and roof extensions of building (BIM Model) in Solibri. In general, these type of shading elements in the building needs to be treated as a shading device (*IfcShadingDevice*) according to IFC schema. However, in Solibri, the parapet wall is represented as a wall element (*IfcWall*) and roof extensions are defined as roof elements (*IfcRoof*). By the verification of IFC STEP file, it is clear that none of the building elements are defined using *IfcShadingDevice* entity and it is observed that even in Revit, there is no option to define any element particularly as a shade.

4.3 Data quality verification in energy simulation model

After verification of the quality of input data using model viewer tool, the verified data is transferred to the energy simulation tool (IES<VE> 2018) (refer to Figure 2). The intent of this process is to investigate the data import capabilities of IES from IFC and to verify the quality of imported data in simulation tool.

4.3.1 Evaluation of Results

The data quality verification is performed by analyzing the results of the data transfer process and the evaluated results are presented in different categories mentioned below.

Import statistics

IES application generates a statistical report after every successful process of data import. This report represents the details about area and volume for each space, elements bounded by the space and its intersections. This statistical report is used to perform a comparison between modeled data and imported data. Based on this comparison, a difference in values of both area and volume between BIM model space and the energy simulation model space is identified. It is noticed that the volume difference between the BIM model and IES model is in a range of 10% - 15% and it may cause the design of over sized building services system in energy simulation.

The difference of area and volume between both models is because of the difference in area calculation process. In IES, area calculation is performed by using center to center distance between the walls whereas in Revit, this calculation is performed using clear distance between the walls. It implies that in IFC import process, IES only imports center line coordinates of the element and places a 2-D virtual surface exactly at the center of the element for energy analysis purposes.

Geometry and Orientation

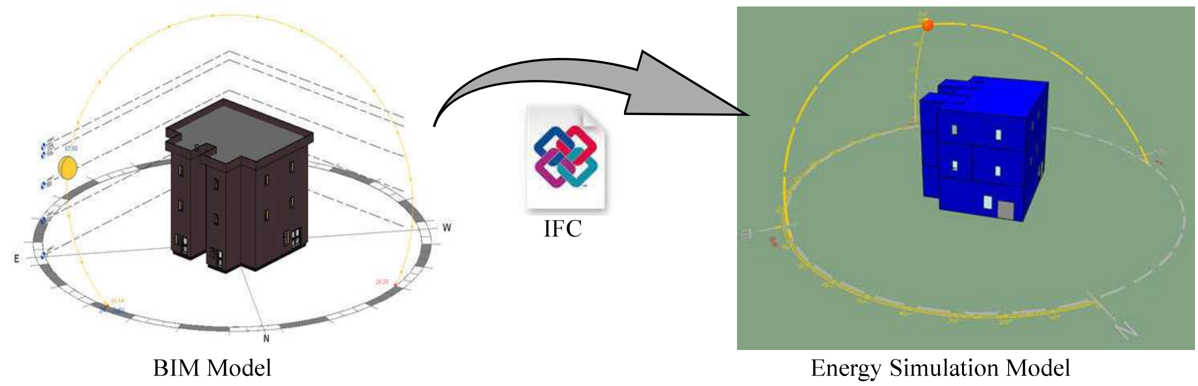

Figure 3: Data transfer from BIM model to energy simulation model

The data transfer methodology using IFC successfully imports the geometry, space and location details of the building to IES. Figure 3 represents the orientation of building which is different when compared to the BIM model. The modeled orientation of the building is 320 degrees to the true north but in IES, the building is oriented at an angle of 40 degrees to the true north. This difference can be observed by comparing the models shown in Figure 3. The error in building orientation may be due to insufficient compatibility between Revit and IFC regarding angle of rotation assigned to the BIM model.

The roof extensions and the parapet wall in the BIM model are not imported to IES from IFC even though the details regarding these elements are present in the IFC file (see Figure 3). The main reason for this issue is that the IES doesn't import elements which are not bounded by any space in the model. The solution for this issue is to define non space bounded elements as local shadings in the model. But, in the case of Revit to IFC export process, these non space bounded elements (roof extensions, parapet wall) are exported as building element (section 4.2) instead of local shadings. This export issue causes the problem of importing those elements into IES.

Construction Details and Thermal Profile

After successful verification of the data in IES, it is observed that the construction details mentioned in the BIM model are not imported to the IES from IFC. By thorough investigation of IFC STEP file, it is noticed that, Revit successfully exported all construction details to IFC but IES is not capable of importing those details from IFC. In the IFC import process, IES is not importing building services systems as this information is not attached to the zones directly. IES successfully imports space types modeled in the BIM model although these are not defined according to IFC schema. With the help of these space types, IES redirects to its' own libraries and assigns similar space types to the spaces in the IES model. Occupant, lighting and power schedules are also not imported from IFC. It is observed that even Revit does not export information regarding schedules to IFC.

5 Conclusion

This research started with the intention of enabling seamless data transfer from BIM model to BES model with the help of IFC file format. In this paper, intensive investigations are performed to identify the information required for energy simulations and on data sharing requirements of IFC to transfer this information successfully. A demonstration of data sharing is performed by selecting an example of an office building and by incorporating all the investigated information needs for energy simulation to this example building. An analysis of the data transfer process is carried out by comparing the demonstration results with the investigated data sharing requirements. The purpose of this comparison is to identify whether the data is transferring to the simulation model according to IFC standard definitions or not. Similarly, a comparison is performed between the data transferred to IES and the modeled data in Revit to identify quality and completeness of the data transfer process. It is observed that IES successfully imports the geometry of elements and details of spaces defined in the building. But on the other hand, some of the information regarding shading elements, material and construction details, and thermal properties linked to space type are not successfully transferred to IES. Similarly, certain space volume differences are found between BIM and simulation models.

Majorly there are some issues with Revit to import the data such as shading element, space types and schedules to IFC file format. This could be due to "export layer set" defined in Revit. This study concentrated on the definition of this export layer set according to data transfer requirements and also on the investigation of lack of entities in IFC for the energy simulation process. This study also concentrates on the failure of IES in case of importing material, construction details from IFC. Furthermore, the research is extended to data transfer activities related to structural analysis domain in terms of identifying the feasibility of adapting IFC for data transfer process between technical specialists in the respective domain.

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